ASSESSMENT OF INDUSTRIAL AND INDUSTRIALLY LOGGED FORESTS OVER NORTH AMERICA: DISTURBANCES, BIOMASS EXTRACTION, AND GROWTH VIGOR

2015 Annual Report

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1. Introduction and Objectives

Tree plantation and other forms of industrial forestry offer vital socio-ecological services to the human society. Because heavily managed tree plantations differ from natural forest ecosystems in many aspects, however, replacing native, natural forests with economically more valuable tree plantations can have many negative environmental impacts (Lugo 1992). In order to assess the role of industrial forestry in biogeochemical cycles, socio-ecological services and environmental systems, the characteristics of these forests, including their geographic distribution, species composition, structure, growth rate, harvest cycle, and timber production, need to be better understood (Houghton 1995; Bradford et al. 2008; Bakermans et al. 2013).

The main purpose of this project is to develop a new high resolution (Landsat 30m) continental analysis of North American industrial forests. Its specific goals include:

1. Develop a 30-year record of industrial forests for North America using temporally dense time series Landsat observations. This record will consist of a suite of 30 m data products, including:
   - **a)** The spatial distribution of both plantation forests and natural forests that experienced industrial logging and harvest, which are mapped into two separate categories,
   - **b)** The year and intensity of each harvest event for each forest patch.
2. Model the growth rates of the industrial forests mapped through objective 1:
   - **a)** Evaluate how these rates vary spatially and along environmental gradients,
   - **b)** Analyze the underlying environmental and management factors that may drive the variability of these rates;
3. Combine the survey-based timber product output (TPO) data (Johnson 2001) with the harvest record developed through objective 1 to produce an annual TPO record for the past 30 years. This should aid in assessing the role of industrial forests in the North American carbon cycle.

North America provides more than 40% of global industrial roundwood production (FAO 2010). National and international statistics suggest that planted forests account for less than 10% of the total forest area in the US and Canada (Smith et al. 2009; FAO 2010). However, industrial forestry practices are employed to extract wood products from more natural, lightly managed forests in this region. More than half of the total timber production in these two countries originates from these lightly managed natural forests (Smith et al. 2009; FAO 2010). Therefore, in this study, i*ndustrial forests include both tree plantations and natural forests that experienced industrial harvest/logging, but the two forest types will be mapped in two separate categories.*

2. 2015 Progress

In 2015, we focused on finalizing the forest disturbance product derived through previous efforts for the conterminous US (CONUS) and making it available to the science community, mapping forest disturbance type/agent, mapping forest structure through radiative transfer model inversion, collecting ground based TPO survey data for all states across CONUS, getting ready for mapping forest disturbance over Canada using Landsat time series observations and the vegetation change tracker (VCT) algorithm. We also conducted in-depth analysis of field plot data collected through the USDA Forest Service Forest Inventory and Analysis (FIA) program. These data provide unique reference information for developing approaches for mapping forest age, structure, and dynamics using satellite observations.

2.1 Distribution of NAFD-NEX disturbance maps

We have finalized the NAFD-NEX (North American Forest Dynamics-NASA Earth eXchange) forest disturbance product. Generated using annual time series Landsat observations and the vegetation change tracker (VCT) algorithm, this product consists of annual, 30-m forest disturbance maps for CONUS from 1986 to 2010. These maps are archived at the Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC), and are available for free download from https://daac.ornl.gov/NACP/guides/NAFD-NEX_Forest_Disturbance.html. Fig. 1 shows the disturbance map for 2002.

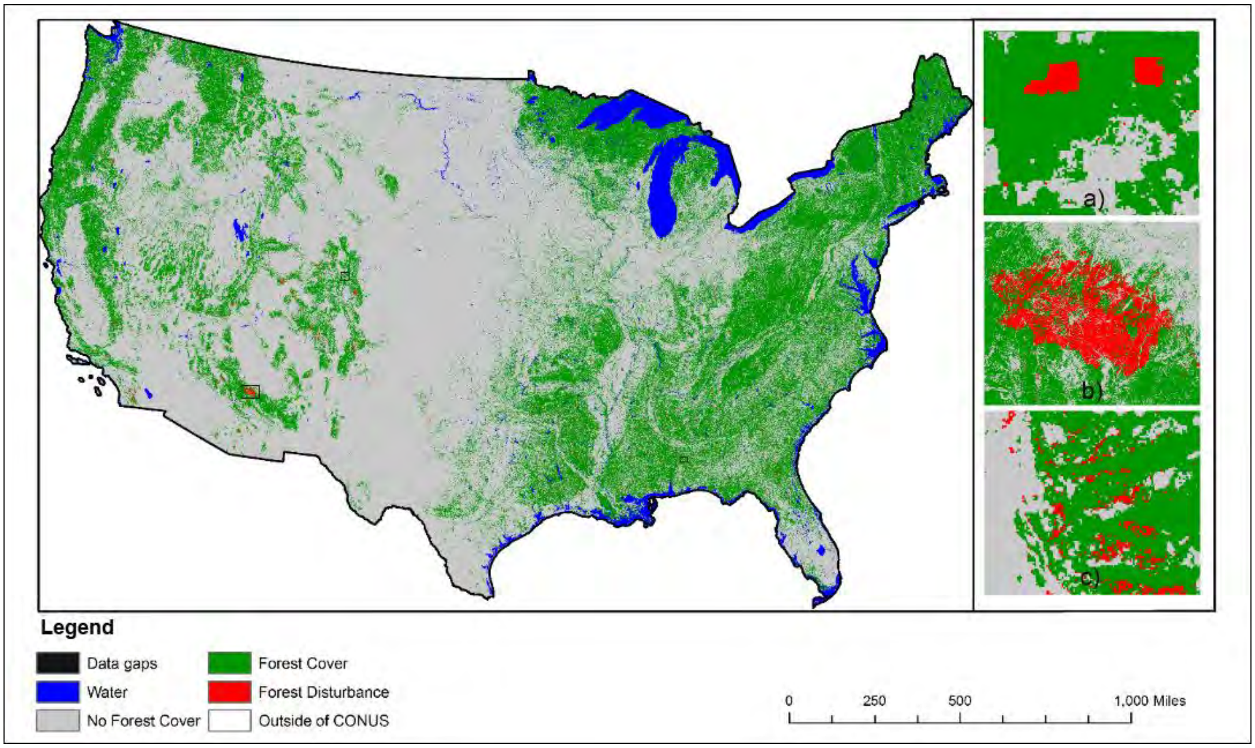

Fig. 1 *An overview (left) and three zoom-in windows (right) of the 2002 NAFD-NEX forest disturbance map available from the ORNL-DAAC (*https://daac.ornl.gov/NACP/guides/NAFD-NEX_Forest_Disturbance.html).

2.2 Mapping of forest disturbance agent/type

Based on the NAFD-NEX disturbance product, we have developed algorithms for identifying the processes that resulted in the mapped disturbances. The disturbance processes considered in this study include harvest/logging, fire, insect/disease, wind storm, and conversion. Fig. 2 shows a preliminary version of the generated disturbance type product. We are currently refining this product, which will also be distributed through ORNL-DAAC when finalized.

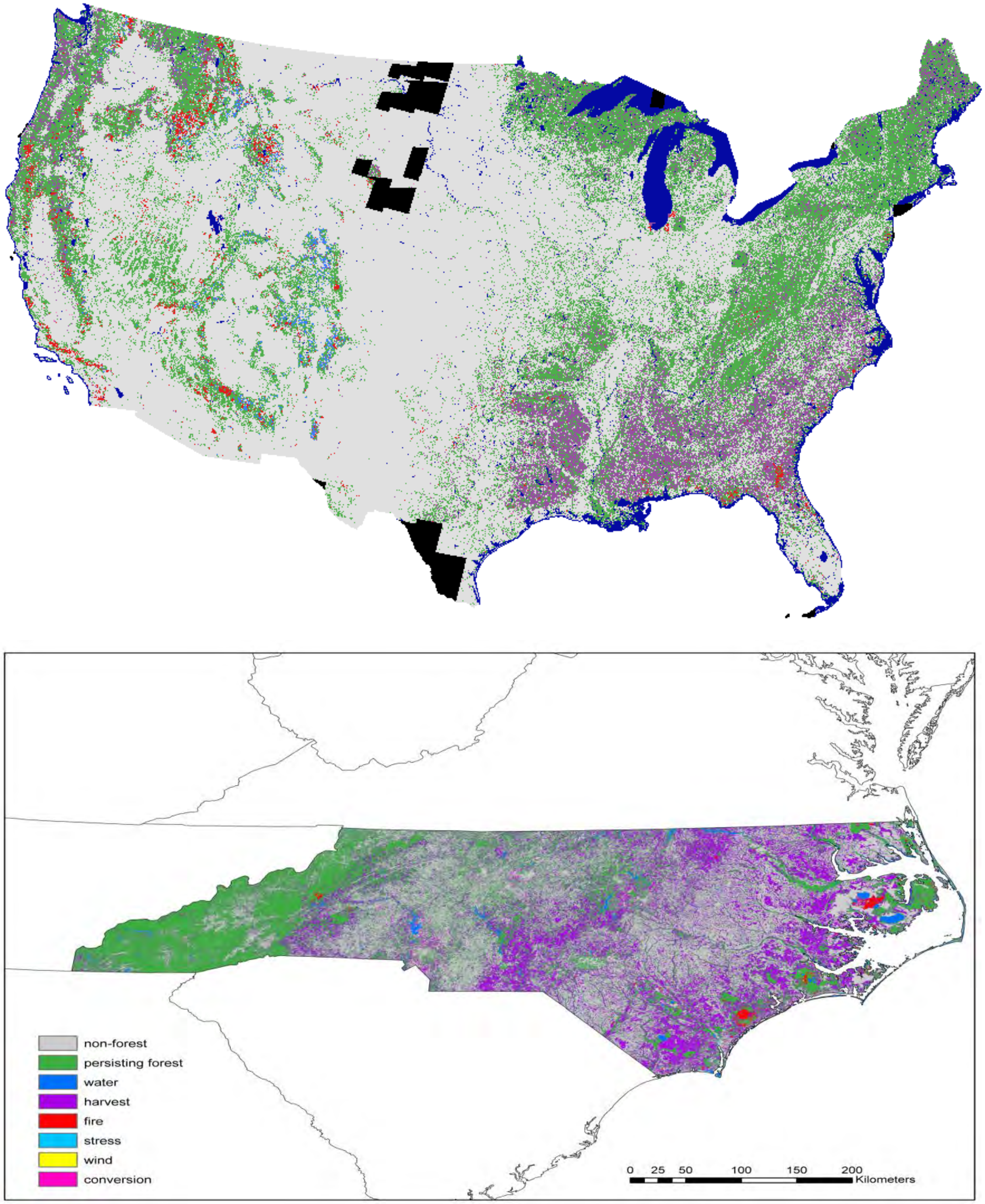

Fig. 2 *Preliminary forest disturbance type map for CONUS (top) and North Carolina (bottom).*

2.3 Forest structure mapping through radiative transfer model inversion

We are developing a novel approach for deriving forest structure variables such as canopy cover, stem area, and biomass using radiative transfer models (RTM). In this approach, we first use radiative transfer models to simulate the reflectance values using structural variables measured by field crew through the USDA Forest Service Forest Inventory and Analysis (FIA) program, which result in look-up-tables that link forest structures to surface reflectance values. For any given Landsat observation, we then search these tables to find the forest structure values that are associated with reflectance values that match that observation (Fig. 3). This approach is being used to produce annual forest structure products across CONUS.

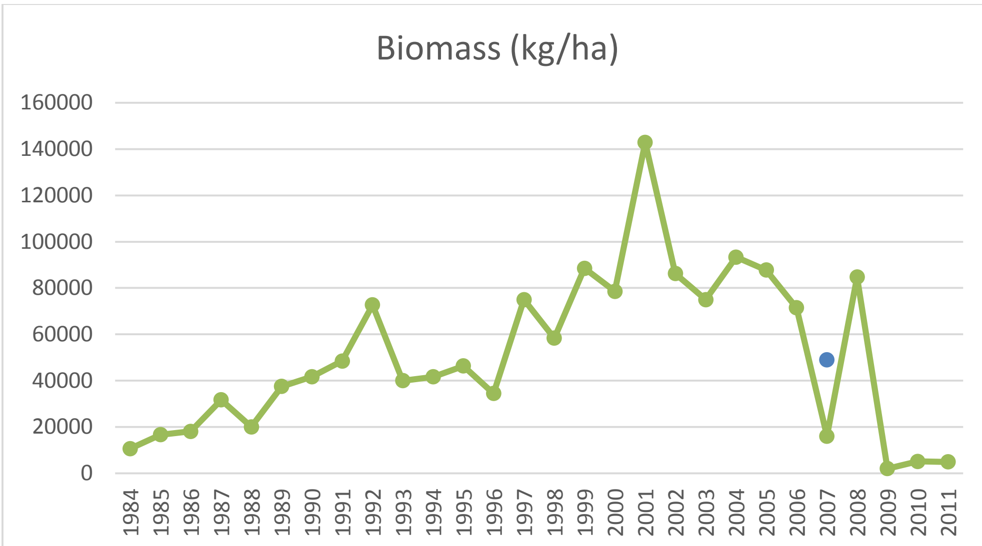

Fig. 3 *Annual biomass values (green line with dots) over an FIA plot derived through RTM model inversion. The blue dot is the reference biomass value according to FIA measurement.*

2.4 TPO data collection

We explored approaches for estimating timber product output (TPO) from Landsat based disturbance products. Initial tests in North Carolina revealed that survey based TPO data are highly correlated with forest disturbance area mapped using time series Landsat observations. Our approaches allowed generation of an annual record of TPO that tracked ground based survey data (Fig. 4) and carbon stored in harvested wood product (HWP) dating back to the 1980s (Fig. 5). These results have led to the development of two peer reviewed journal articles (see section 2.7).

We are in the process of applying the developed approaches to other forested states over CONUS. We have identified and downloaded ground based TPO survey data for most of those states. The ground based data will be used together with the NAFD-NEX disturbance products to develop the models that are needed to estimate TPO for the years that did not have ground based survey data.

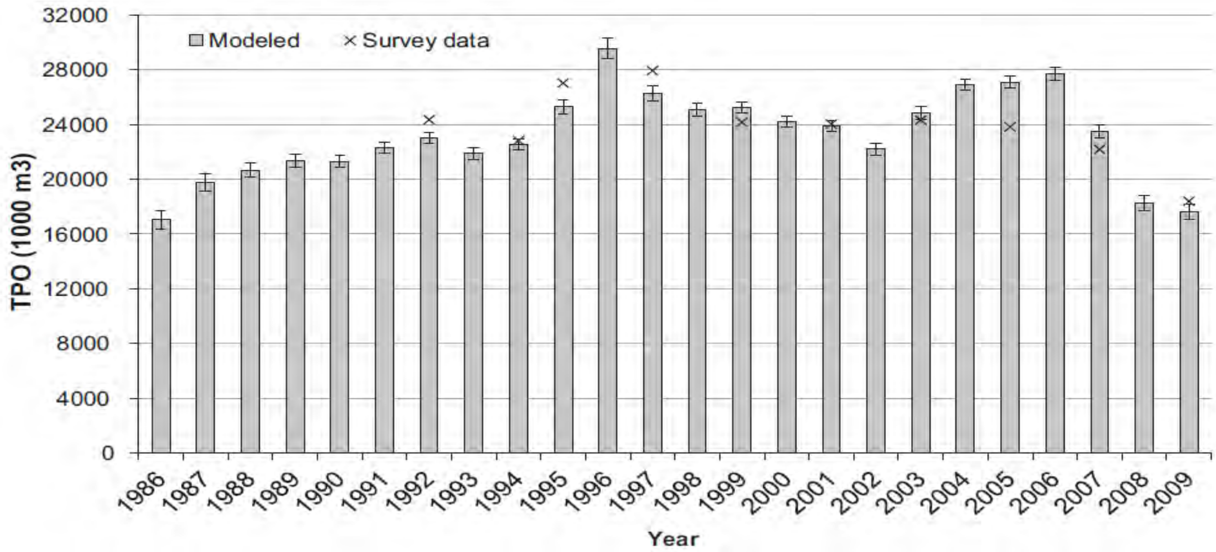

Fig. 4 *State level TPO estimates derived based on VCT disturbance products as compared to ground survey data, with error bars indicating the 95% confidence interval of those estimates.*

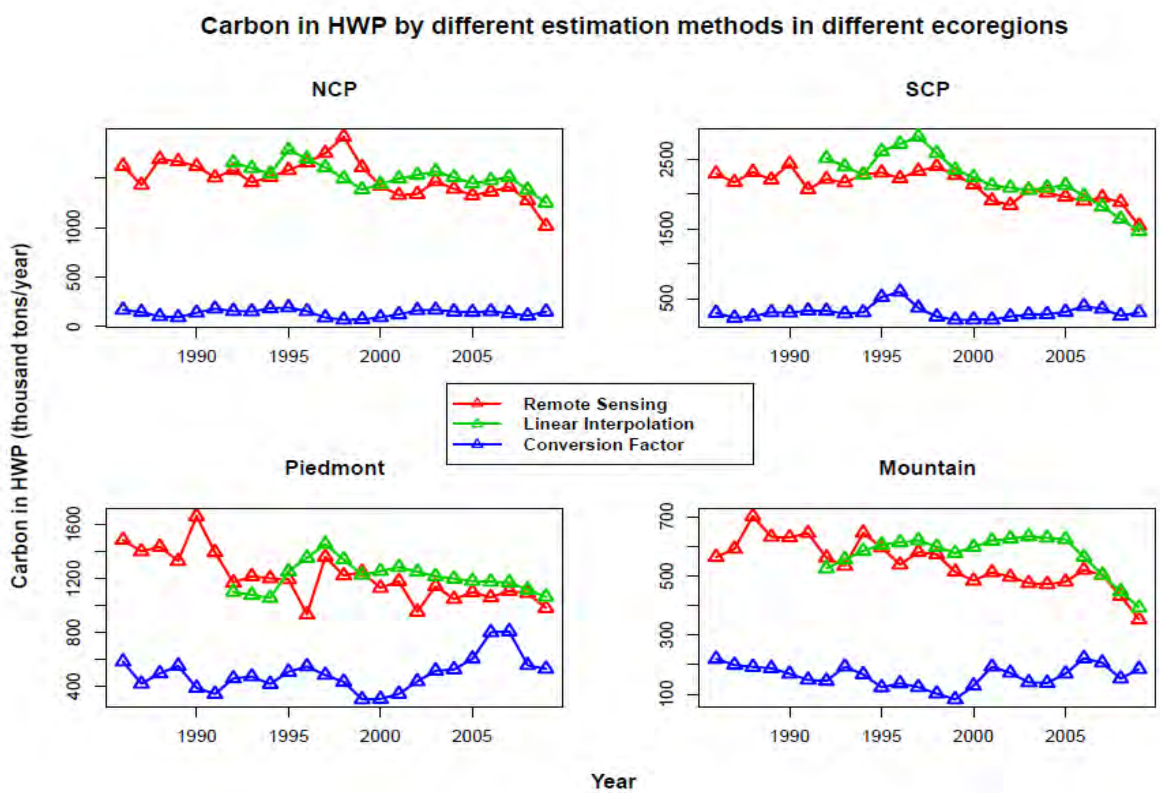

Fig. 5 *Comparison of annual records of carbon in harvested wood product (HWP) derived over the Northern Coastal Plain (NCP), Southern Coastal Plain (SCP), Piedmont, and Mountain regions of North Carolina based on Landsat-based disturbance products (Remote Sensing), temporal interpolation of ground survey data (Linear Interpolation), and a Conversion Factor method.*

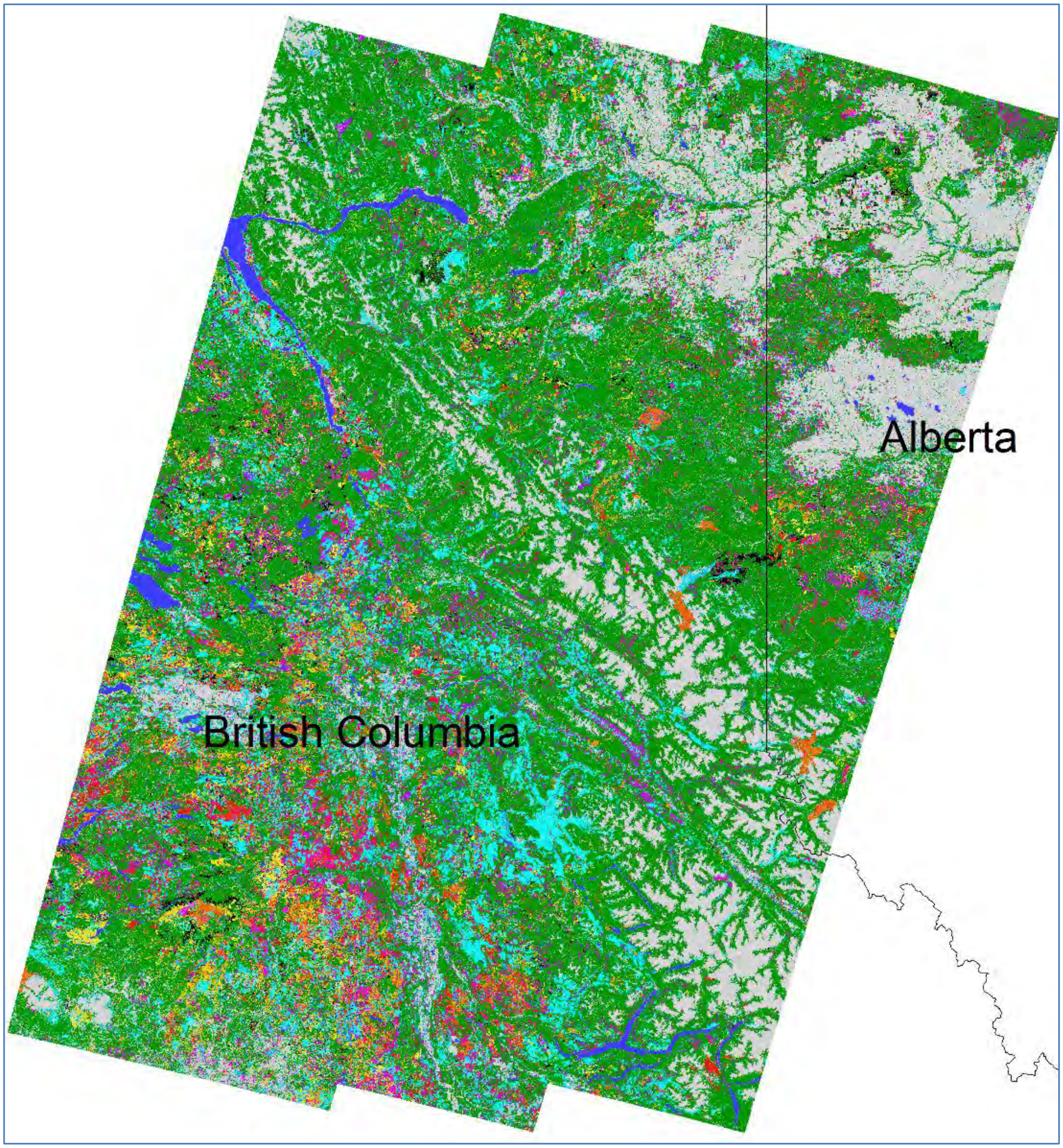

Fig. 6 *Forest disturbance map generated using time series Landsat observations and the vegetation change tracker (VCT) algorithm over western Canada.*

2.5 Forest disturbance mapping over Canada

We have adapted the VCT code for mapping forest disturbance over Canada and have tested it over several large areas in eastern, central, and western Canada (Fig. 6). The updated algorithm is running on NEX to produce forest disturbance products for all forested areas over Canada.

2.6 In-depth analysis of FIA plot data

Field plot data collected through the FIA program are critical to this project. We have established MOUs with all four FIA regions, which now allow us to use FIA plot data across CONUS (Fig. 7).

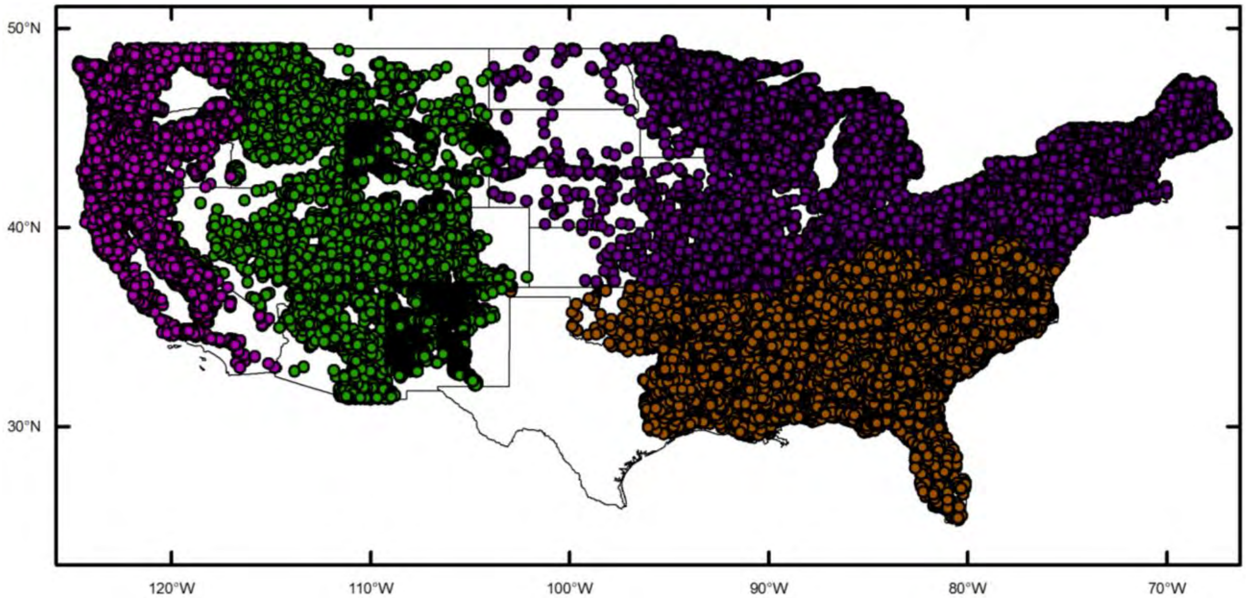

Fig. 7 *Distribution of forested FIA plots over CONUS. The four colors represent the four FIA regions over CONUS (dark purple – North, dark brown – South, green – Rocky Mountain, and pink – Pacific Northwest). It should be noted that this chart only shows the approximate locations of the FIA plots, which are known to the public.*

The FIA data provide rich information on the forests in the United States, including forest type, density, height structure, and stand age, among others. Fig. 8 shows the stand age distribution of forests in the four FIA regions in CONUS. It reveals that both the southern region and the Rocky Mountain region are dominated by two age groups. In the southern region one group peaked at about 20 years and the other at about 60 years, whereas in the Rocky Mountain region the two groups peaked at about 20 years and 100 years, respectively.

As of today, all FIA plots have been measured at least twice since 2000. These repeat measurements provide ground-based observations on disturbance intensity and forest growth rates. We will use these datasets as reference for modeling forest age, structure, and biomass change. Because some of the FIA data may contain certain levels of errors, we are currently developing protocols for identifying those erroneous plots such that they will be excluded from the modeling analysis.

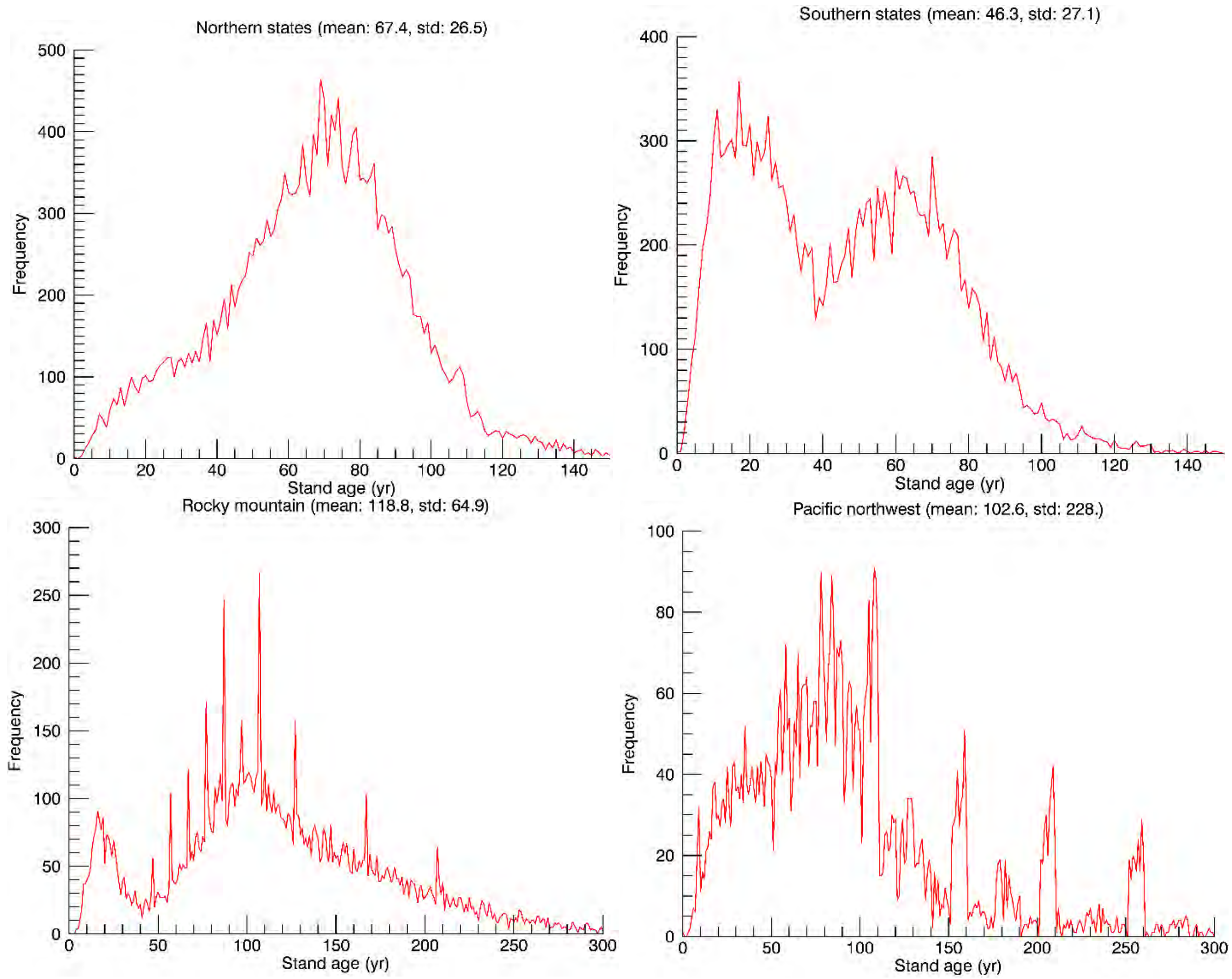

Fig. 8 *Distribution of forest stand age in the four FIA regions as represented by FIA plot data. See Fig. 7 regarding the four FIA regions.*

2.7 Publications and conference presentations

Cohen, W.B., Yang, Z., Stehman, S.V., Schroeder, T.A., Bell, D.M., Masek, J.G., Huang, C., & Meigs, G.W. (2016). Forest disturbance across the conterminous United States from 1985–2012: The emerging dominance of forest decline. *Forest Ecology and Management, 360*, 242-252

Huang, C., Ling, P.-Y., & Zhu, Z. (2015). North Carolina's forest disturbance and timber production assessed using time series Landsat observations. *International Journal of Digital Earth*, 1-23

Ling, P.-Y., Baiocchi, G., & Huang, C. (2016). Estimating annual influx of carbon to harvested wood products linked to forest management activities using remote sensing. *Climatic Change, 134*, 45-58

Zhao, F., Huang, C., & Zhu, Z. (2015). Use of Vegetation Change Tracker and Support Vector Machine to Map Disturbance Types in Greater Yellowstone Ecosystems in a 1984 - 2010 Landsat Time Series. *Geoscience and Remote Sensing Letters, IEEE*, 1-5

Neigh, C.S., Masek, J.G., Bourget, P., Rishmawi, K., Zhao, F., Huang, C., Cook, B.D., & Nelson, R.F. (2016). Regional rates of young US forest growth estimated from annual Landsat disturbance history and IKONOS stereo imagery. *Remote Sensing of Environment, 173*, 282-293

Rosette, J., Cook, B., Nelson, R., Huang, C., Masek, J., Tucker, C., Sun, G., Huang, W., Montesano, P., & Rubio-Gil, J. (2015). Sensor Compatibility for Biomass Change Estimation Using Remote Sensing Data Sets: Part of NASA's Carbon Monitoring System Initiative. *Geoscience and Remote Sensing Letters, IEEE, 12*, 1511 - 1515

Chengquan Huang, Feng (Aron) Zhao, Pui-Yu Ling, Xin Tao, Karen Schleeweis, Samuel Goward1, Andrew Michaelis, Jeffrey Masek, and Jennifer Dungan, 2015, Dynamics of Industrial Forests in Southeast United States Assessed using Satellite and Field Inventory Data, AGU Fall Conference, San Francisco, December 14-18, 2014.

Chengquan Huang, Feng (Aron) Zhao, Samuel Goward, Karen Schleeweis, Andrew Michaelis, Jeffrey Masek, Jennifer Dungan, Warren Cohen, Gretchen Moisen, and Khaldoun Rishmawi, 2015, Where are the forests in the United States “not disturbed” over a quarter century?, Poster presented at the AGU Fall Conference, San Francisco, December 14-18, 2014.

3. Plan for 2016

We will focus on the following in 2016:

- Finish forest disturbance mapping over forested areas in Canada;
- Assess the growth rates of industrial forests in the conterminous US;
- Produce annual TPO records for the conterminous US.

4. References

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Johnson, T.G. (Ed.) (2001). *United States timber industry—an assessment of timber product output and use, 1996*. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station.

Lugo, A.E. (1992). Comparison of Tropical Tree Plantations with Secondary Forests of Similar Age. *Ecological Monographs, 62*, 1-41.

Smith, W.B., Miles, P.D., Perry, C.H., & Pugh, S.A. (2009). Forest Resources of the United States, 2007. In (p. 336). Washington, DC: U.S. Department of Agriculture, Forest Service.